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RESEARCH FOR THE DEVELOPMENT OF WATER QUALITY CRITERIA FOR AQUATIC LIFE

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Research for the Development of Water Quality Criteria for Aquatic Life

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The Problem

It is now recognized that water pollution is an important problem, that it becomes more widespread and serious as population and industry expand, and that something must be done if we are to save our aquatic life resources and maintain their productivity. In the past there has been a great deal of groping and uncertainty in approaching this situation and a general lack of understanding of the details and ramifications of the over-all problem. In our efforts for the abatement of pollution, only a few clearcut objectives have been established. We lack knowledge as to what our objectives should be. We have scant knowledge of the levels of various wastes which can be tolerated by aquatic organisms for short periods and practically no information on concentrations that are safe when such wastes are continually discharged. The reason is that we have not definitely determined either the environmental requirements of aquatic organisms or the concentrations of various materials which can be added to our waters without adversely affecting the survival, growth, reproduction or general well being of the important members of the aquatic biota.

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The need to develop water quality criteria for aquatic life is stated. Continuing research is essential to obtain data for defining the environmental requirements for maintenance of the aquatic biota. With adequate water quality critera for aquatic life, objectives of pollution control can be clear and understandable, treatment needs indicated, public opinion effectively brought to bear on abatement, regulations made uniform, and violations clearly demonstrated.

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We need to know more about the maximum concentrations of dissolved toxicants and the minimum concentrations of dissolved oxygen that fish and other aquatic organisms can withstand for short periods, and to what level water temperatures may be raised for short and extended periods without adversely affecting aquatic life. Most important of all, we need to know maximum or minimum concentrations of dissolved materials (solids, liquids, and gases) which are permissible or are required for aquatic life under conditions of continuous exposure. Lacking these facts and having no clear cut objectives for pollution abatement we cannot effectively and efficiently meet the pollution problem and make the best use of our water resources. A pertinent, well-planned, adequate research program is needed.

For too long we have had the cart before the horse. A research program which deals with basic problems is required: First we must determine the environmental conditions which are essential for producing a suitable crop of the aquatic organisms we desire and we must determine concentrations of the various wastes which do not adversely affect the production of that crop. Without such knowledge we cannot state what conditions must be maintained in our waters or to what extent wastes must be treated. Such knowledge is the basis upon which water quality criteria are established.

The objective of water quality criteria for the protection of aquatic life is to maintain or restore those surroundings and living conditions which are essential for the survival, growth, reproduction, and well being of aquatic life. These criteria necessarily must be based on a knowledge of the habitat or environmental requirements. Thus the environmental requirements of all the important aquatic organisms and the effects of various wastes on their environment must be determined.

This is a difficult and involved task which will require an enormous amount of time and effort. Furthermore, since our growing, ever more diverse industries are continually producing new, more toxic, and persistent wastes, the problem will be a continuing one. While attempting to catch up on our backlog of problems we must recognize and keep abreast of new ones. In this ever-changing situation we cannot wait for all the answers before we begin to formulate water quality criteria. As knowledge becomes available it must be used to formulate tentative criteria for the protection of fishes and other aquatic life. An effort to meet this problem was made in 1956 when tentative water quality criteria were suggested with the idea they would be modified by later research findings (Tarzwell 1957). Additional data are needed to evaluate, modify, and improve these criteria.

The interrelation of various factors in the environment, such as temperature, dissolved oxygen, and carbon dioxide must be determined. We know that more oxygen is needed at higher temperatures and at higher carbon dioxide concentrations. However, there is little definite information on how high the temperature may go under different dissolved oxygen levels, or how much dissolved oxygen should be present at different temperatures and concentrations of carbon dioxide to allow a fish to maintain its position against the current, catch its food, elude its enemies, reproduce and carry on other essential activities. This information must be obtained for all the important food and game fishes and the organisms in their food chains. Considerable information is available in regard to trout, but data concerning other fishes are meager and spotty. The requirements of the fish food organisms and many marine organisms are virtually unknown.

Collecting this information will take time and money but such information must be made available if marine and fresh water fisheries are to be protected.

Our commercial fisheries now have an annual yield of about five billion pounds. These products provide a valuable source of high-protein, low-fat, high-mineral foods so much needed in our diet today. While our commercial fisheries are an important food resource our sport fisheries are an even more valuable recreational asset, having a value in the billions of dollars. Those acquainted with agricultural developments know the tremendous amount of effort and research which has been expended in order to place this industry at its present high level. Similar efforts, on a smaller scale, are needed to determine the requirements of our aquatic crops and the means to protect them from water pollution.

Accomplishments in the control and abatement of water pollution have not kept pace with needs and developments. Attainments have been entirely inadequate for meeting the national problem, chiefly because insufficient resources have been devoted to research in this area.

A Research Program

The problem of protecting our aquatic life from pollution is of recreational and economic importance. To solve this problem water quality criteria must be developed that will insure the survival, growth, reproduction, and general well being of marine and freshwater organism. Since the purpose of these criteria is to restorate or maintain the required environment, they must be based on a thorough knowledge of the essential living conditions of those fishes and other organisms we are endeavoring to protect.

To attain this knowledge, research, investigations and field studies must be carried out to determine the requirements of the great variety of aquatic organisms which must be protected. The guiding principle in such research must be the securing of data basic to and essential for the setting up of water quality criteria for aquatic life.

In initiating such a research program the first task is the selection of adequate water supplies for these studies, ones which are of suitable quality and quantity and are free of manmade wastes. Further, there must be evidence that the supplies will be continuous in the foreseeable future and will not be contaminated with wastes due to expanding population or industry.

Probably the best way to insure an uncontaminated fresh water supply is to choose one which originates in a National Forest, National Park, or Wilderness Area. The ideal location is one where there is a protected, permanent soft water stream and a hard water spring nearby. Since the water supply is of paramount importance the best obtainable water supply must be chosen and the research facilities built around it. Considerable land will be needed for ponds, raceways, experimental facilities, and buildings.

A site on a shore line devoid of industrial development and sparsely settled would be advisable for the marine facility. Perhaps a location in or near an extensive federal wildlife refuge would be desirable. Unpolluted sea water and a flowing water system are required for the various static and continuous flow bioassay and other tests and to maintain supplies of test organisms. The marine facility should be located where a continuous supply of uncontaminated salt water can be obtained at a minimum cost.

Fresh water also should be readily available for the needs of the station and for use as a diluent for salt water in studies of estuarial problems. If possible the station should be within easy travel distance to areas having pollution problems so that samples and test animals can be secured. The station also should be located where a protected docking area can be established for the boats required in the work. The site should be in the vicinity of fishery operations since contact with commercial fishermen is desirable in order to have first-hand knowledge of their problems resulting from the pollution of estuaries and inshore marine areas. The pollution of inshore areas along the Atlantic and Gulf Coasts, where shrimp and important commercial and marine sport fishes breed or have their nursery areas, is a problem requiring immediate attention. Allowable limits of wastes must be established if these fisheries are to be preserved. Similar studies are needed for oysters, clams, and other important species in all coastal areas having pollution problems.

In approaching the problem it is well to classify the types of wastes and develop research plans for the investigation of each. Pollutants generally are classified according to their source, such as sewage or industrial wastes. In a research program directed toward the abatement of pollution, however, they can probably best be classified according to their effects on the receiving water. Under such a system all pollutants can be included in one or more of the following categories:

1. Oxygen depleting or putrescible wastes.
2. Toxic wastes.
3. Inert inorganic and organic materials.

4. Wastes with a significant heat content, i. e., hot water.

5. Contaminants, materials causing tainting of fish flesh.

6. Radioactive wastes.

Research plans should include studies to determine the effects of each of these types of pollutants on important fresh water, marine and estuarial organisms; the amounts or concentrations of wastes that are rapidly lethal to these organisms; the maximum or minimum amounts that can be tolerated for short periods; and the amounts or concentrations which are safe under conditions of continuous exposure and do not interfere with the production of a suitable crop. These studies will provide data essential for the formulation of water quality criteria for the protection of aquatic life.

Oxygen Depleting or Putrescible Wastes

Dissolved oxygen requirements of aquatic organisms have received more attention than any of the other environmental factors. Minimum dissolved oxygen concentrations that can be resisted by fish for short periods have been studied frequently. Often resistant species have been used at low temperatures under conditions of inactivity. Since the tests usually are of a few hours duration, the fish are not fed and do not carry out normal activities. Evaluation is based upon survival alone with no regard to the condition of the fish at the end of the test. Such tests do not indicate actual oxygen requirements for normal existence and do not measure the amount of oxygen required for the survival of the species. In the past the results of such tests have caused misunderstanding regarding oxygen requirements and have led to misconceptions and extended arguments as to

such requirements and have tended to hinder the establishment of adequate criteria.

Long-term studies under conditions similar to those found in nature are essential for the establishment of dissolved oxygen criteria for fresh water, marine and estuarine organisms. Since there are many thousands of organisms involved, attempts should be made to study communities and to give primary attention to the most important sport and commercial fishes and shellfish and to the organisms in their food chain. Attention should also be directed toward determining the multiple effects of other environmental factors on dissolved oxygen requirements. In these studies stress should be placed on the effects of temperature, carbon dioxide, hydrogen ion concentration, and dissolved materials. There is special need for information on the amount of DO required by different species of fish, for normal activity at maximum allowable temperatures and under carbon dioxide concentrations that may be found in waters enriched with sewage and other organic wastes. In addition to determining lethal levels, and minimum concentrations which can be resisted for short periods without significant harm, studies should be made of the adverse effects of low but non-lethal levels of dissolved oxygen. Studies of the long-term effects of reduced oxygen on survival, growth, reproduction, and the success and rate of embryonic development are of prime importance. At least some of these studies should be made under conditions similar to those in nature; that is, with diurnal variations in DO, temperature, CO_2, and pH. The effects of decomposition products, such as methane, ammonia, and hydrogen sulphide, need to be determined. Special equipment must be devised and new methods

developed for these studies. Although a few multiple factor studies have been made with marine and estuarine forms data on fresh water forms are very meager. Artificial streams or raceways are essential for certain studies with fresh water forms and special continuous flow equipment is needed for the investigation of the requirements of marine organisms. Field studies should be made in selected areas to test and evaluate laboratory findings and the adequacy of suggested criteria.

Toxic Wastes

Acute kills of fishes due to spills or slugs of toxic wastes receive considerable publicity and are generally condemned, especially when they are recurring. Such kills, while important and spectacular, may not be as important as the slow insidious destruction of aquatic populations without any notable fish kill. Of prime importance in developing water quality criteria for the protection of aquatic life is the determination of levels or concentrations of toxic wastes which kill only after extended exposure, or which reduce the general well being and productivity of the population without destroying it. Methods have been developed for the determination of acute toxic effects of industrial and other wastes by short-term bioassays. These are described in the 11th edition of Standard Methods for the Examination of Water and Wastewater. These short-term studies provide a means for determining acute toxicity of a waste or chemical to selected species and can be used also to indicate comparative acute toxicities. The results of these studies are expressed as the median tolerance limit (TL_m) which is that concentration of a material that kills half the test fish in a specified time; e. g., the 96-hour TL_m is that concentration of a material

which will kill half the fish in 96 hours. The TL_m value does not indicate concentrations which are safe for even short periods, let alone under conditions of continuous exposure.

Long-term continuous flow studies are needed to determine cumulative effects of the toxicants and concentrations which are neither lethal nor apparently significantly harmful; to determine the effects of wastes on reproduction, and especially on the sensitive developmental stages such as fish fry; and to determine variations in toxicity among the different species, and the physiological and histological effects of sublethal concentrations. In determining the concentrations of toxic wastes which are not harmful to the biota under conditions of continuous exposure consideration must also be given to diurnal and seasonal variations occurrring in nature, such as fluctuations in DO, CO_2, pH, temperature, and dissolved materials. Field tests are, therefore, necessary to test the laboratory findings and water quality criteria based on them.

Inert Inorganic and Organic Materials

Materials eroded from the land are our most universal water pollutant and perhaps the most important one. Wastes from placer and hydraulic mining, gravel washing, mining operations, and other industrial operations also cause unfavorable conditions in our waters. Silt and other settleable solids cover spawning areas, reduce the production of bottom organisms in gravel bottom streams, fill pools, destroy cover, choke streams and fill ponds, lakes, and reservoirs. Turbidity due to settleable and suspended materials limits light penetration and thus the photosynthetic activity of algae; this results in decreased production of plankton and affects the

whole aquatic food chain. Muddy waters, which are less favorable for the game fish that feed by sight, can be responsible for decreases in the quality of fish populations by favoring the coarse species. Suspended materials may be directly detrimental to fishes and other aquatic organisms through damage to the gills or other structures.

To formulate criteria for settleable and suspended solids, data are needed on the direct and indirect effects of turbidity on fish populations and on the amounts of settleable solids which can be added to various types of streams and other waters without significantly decreasing productivity. Data are also needed on the amount of light essential for the growth of plankton and rooted aquatics and the effects of settleable solids in removing plankton. Correlations should be made between turbidity and light penetration. More extensive studies are needed on the direct harmful effects of different types of suspended matter to the gills of fishes; on the amount of silting which can be tolerated by the benthic organisms in the marine and estuarine environments; and to determine levels of settleable solids and turbidity which are not detrimental to the life processes and do not reduce the productivity of important marine and estuarial invertebrates.

Wastes With a Significant Heat Content - Hot Waters

The increase in the demand for electircal power and the expansion of industries requiring cooling waters are adding ever-increasing amounts of heat to our waters. In some areas the amounts have exceeded the capacity of the streams to receive them and stream termperatures have reached levels unfavorable for aquatic life.

Data are needed on maximum temperatures that can be tolerated for short periods by aquatic life and on temperatures which can be maintained continuously without harm to the biota. Data are also needed on acclimation to high and low temperatures, the effects of sudden changes in temperature, the amount of change that can be tolerated, the avoidance reactions to certain temperatures, and the effects of high temperature areas on migration and the repopulation of areas by drift organisms. Factors such as DO and CO_2 also must be considered.

Since the temperature tolerance of different species may vary widely, it will be necessary to study not only the requirements of all the important organisms but also those of the organisms on which they feed. A series of ponds and artificial streams into which heated waters can be added continuously and in which the variables and their multiple effects can be studied and evaluated is a prerequisite for determining long-term effects of temperature and the requirements of different life history stages. Special consideration must be given to the effects of elevated temperatures on spawning, growth, hatching of eggs, survival, and development of the fry.

Temperature criteria will vary not only with the species concerned but also with the section of the country involved. Separate criteria will be required for fresh waters that contain cold water species, warm water game species, and coarse species. In the marine environment even slight changes in temperature can be important, and criteria may have to be established for different regions or coastal areas.

Contaminants that Taint Fish Flesh

One result of pollution which may have a significant effect on fisheries but has received little attention in the past is the tainting of fish flesh by sublethal concentrations of chemicals or wastes. There is a definite need for a reasonably standardized procedure for measuring this effect and for determining concentrations of various materials which produce no effect.

Tainting, or off flavor, has been reported in fish from some of our large rivers (Ohio, Mississippi, Mohawk, Hudson, etc.), from some areas of the Great Lakes, and from many smaller lakes, ponds, and streams. This tainting has been attributed to oil refineries, pulp mills, chemical industries, oil and gasoline spillage from barges, operation of outboard and other motors, use of herbicides such as 2, 4-D, or other causes. The problem is magnified when it is considered that a few tainted fish may seriously affect the marketing of fish from an extensive commercial fishery. Sport fishing is greatly curtailed even when game fish populations are abundant if fish are tainted and unpalatable.

Tainting problems also occur in marine and estuarine waters where fish and other edible aquatic animals such as oysters, clams, crabs, etc., may be affected. The same principles and techniques developed in fresh water studies may be applicable to marine situations.

Radioactive Wastes

Radioactive wastes probably will become a more important pollution problem as the number of atomic power stations increases and radionuclides are more widely used in industry. Since certain members of the biota can

concentrate these materials to levels many times higher than those in the surrounding water, some species may be used as monitoring tools. Radioactive materials can be used as research tools to trace toxicants, to determine their buildup and location, their stability in the environment, and the amount to which the organisms are exposed. To develop criteria in this area studies are needed to determine the buildup of radioactivity in the flesh of food animals, the passage of radioactivity through the food chain, and any direct harmful effects to the biota.

Other Studies

Physiological Effects of Toxicants

In the past many fish kills have occurred for which neither the toxicant nor its source could be demonstrated. Little is known concerning the pathological or physiological changes in fish which may be caused by toxic substances. Methods for determining the cause of fish kills by an examination of the fish would be of great value in the abatement of pollution.

Studies to determine specific physiological changes that occur when fish are exposed to lethal or sublethal levels of various toxicants are of outstanding importance in determining the cause of fish kills. Radioactive tracer techniques may be of value in some situations for locating depositions of a toxicant. Histological, histochemical, chemical or other methods also can be used to detect specific changes or damage that may occur.

This information would be of great value in determining the source of materials causing fish kills, in establishing responsibility for kills, and as an aid in developing application factors for industrial wastes and other toxicants.

Biological Indicators of Pollution

In the course of carrying out toxicity and other studies to determine the environmental requirements of a large number of organisms, data must be obtained on the maximum and minimum environmental conditions which they can tolerate. These data will define limiting environmental conditions for various organisms and will indicate the water quality required for their existence and well being. When these conditions are known, the presence or absence of these organisms will in turn indicate the extremes of environmental conditions which have prevailed during their life. With these data available, these organisms may be used as biological indicators of environmental conditions in streams, reservoirs, lakes, estuaries, and the marine environment. Such information will be of great value in stream surveys for indicating pollutional zones, severity and extent of stream pollution, and the degree of stream recovery. These data, coupled with methods for the determination of the cause of fish kills, will be invaluable in pollution surveys and the abatement of pollution.

Value of Water Quality Criteria

When based upon detailed, well-planned, and adequate, well-documented studies, water quality criteria for aquatic life can be of great value in the detection, evaluation, and abatement of pollution. They will serve to:

1. Define the objectives to be attained in pollution abatement and in the restoration and maintenance of the aquatic environment.
2. Define the essential objectives of waste treatment and serve as the basis for evaluating different treatment methods for maintaining water quality.

3. Inform the general public of the requirements for the protection of aquatic life and the objectives which must be attained for the abatement of pollution. Such information will enable public opinion to be a constructive and potent force in the abatement of pollution.

4. Promote the adoption of more uniform regulations. Criteria adequately documented by research data will probably be adopted by a number of states. If this should occur it would make it more difficult to use the desire of states or communities for industrial development to secure concessions in waste treatment at the expense of our water resources.

5. Promote the abatement of pollution by providing a firm basis for legal actions. When widely accepted, water quality criteria will clearly define pollution and eliminate long, time-consuming arguments as to what levels or concentrations are or are not harmful. In the absence of accepted criteria each legal action involves arguments as to proof of levels which are harmful. Usually the results of short-term studies carried out with resistant species in static conditions where the fish are inactive, not fed, and the environmental conditions not under test are very favorable, are introduced as evidence. In such studies concentrations of toxicants or environmental conditions in which the test species can resist death for a time through adaptation, inactivity, and fasting, and in which no account is taken of the condition of the test organisms at the time of the conclusion of the study, are

no measure of conditions required for the survival of the species or the production of a crop. Thus, in the absence of exact data or concentrations which are safe under conditions of continuous exposure, the short-term levels are accepted and the case is lost. When accepted water quality criteria are available, the only question will be -- Are or are not the criteria being met?

Summary

At present we do not have exact knowledge of the amount and character of waste treatment needed in order to maintain environmental conditions which are favorable to and essential for the perpetuation of aquatic life in our marine and fresh waters. This is due to the fact that we do not know definitely the environmental conditions that must be provided for the maintenance of the aquatic biota. We do not know all the objectives to be attained for pollution abatement. Well-planned, efficient, comprehensive, and continuing research programs are essential to secure data needed to define these environmental requirements. These studies must be on a scale adequate not only to deal with the great backlog of problems that have accumulated but also to keep abreast of the ever-increasing new wastes that are discharged to our waters.

Research must be carried on with various types of pollutants to determine levels that can be resisted for short periods, and concentrations or amounts which do not interfere with the survival of the biota and the production of a crop under conditions of continuous exposure. In planning such research programs a prime essential is an adequate and suitable water supplies for experimental studies. These water supplies must be free from

man made pollution and protected from such pollution in the foreseeable future. In studies to determine environmental requirements of aquatic life every effort should be made to simulate natural conditions in the tests, and the multiple environmental factor approach should be used. All major findings should be field tested before they are used as the basis for water quality criteria for aquatic life.

Since there is an ever increasing flood of new wastes such research is a continuing task which is never completed. In view of this situation it is believed that we should establish tentative criteria based on the data we now have in order to use it effectively for the protection of the resource. In this way all data will be used as it becomes available and criteria can be established or modified in the light of current knowledge. Adequate, well-documented water quality criteria can be of great value in the abatement of water pollution; without them pollution cannot be efficiently detected or effectively controlled, and abatement attempts must of necessity be hit or miss and uncoordinated. With adequate criteria, objectives are clear cut and readily understandable, treatment needs are indicated, public opinion can be an effective force in pollution abatement, a basis is provided for uniform regulations, and pollution is defined so that violations can be clearly demonstrated in court.

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